

# Endovascular Repair of Thoracoabdominal Aortic Aneurysms with Fenestrated-Branched Stent-Grafts

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The standard surgical approach to thoracoabdominal aneurysms is considerably demanding, and outcomes correlate with the number and severity of associated comorbidities.<sup>1</sup> Many large studies have reported mortality rates ranging from 7% to 17%. Cardiac, neurologic, respiratory, and renal complications limit the number of patients who are eligible for open surgery. Recent advances in operative technique and use of adjunctive measures for spinal cord protection have decreased, but not eliminated, the devastating complication of paraplegia. Nonetheless, other peri-procedural complications still exist due to the invasiveness of open thoracoabdominal repair. Endovascular stent-grafting has been applied to the treatment of infrarenal abdominal and descending thoracic aortic aneurysms with success.<sup>2</sup> A low risk of death and paraplegia after endovascular repair of descending thoracic aneurysms has been reported. Only recently have devices become available for the endovascular management of thoracoabdominal aortic aneurysms where there is extensive involvement of the visceral segment. The potential benefits from endovascular repair include avoidance of aortic cross-clamping and major incisions, minimization of blood loss, diminished postoperative pain, and limitation of visceral, renal, and spinal cord ischemia.

We have been actively involved with the development of fenestrated and branched stent-grafts to target this high-risk patient population with thoracoabdominal aortic aneurysms.<sup>3</sup> The branched thoracoabdominal stent-graft is a modular system based on the Zenith stent-graft (Cook Inc., Bloomington, IN). The main body component is a custom-

designed straight or tapered device with reinforced fenestrations and/or standardized directional helical branches precisely chosen to correlate with the patient's target vessel anatomy based on radiographic assessment of the visceral ostial geometric relationships. Reinforced fenestrations are mated to balloon-expandable covered stents (Jomed; Abbot Labs, Abbott Park, IL), while the directional branches are mated to self-expanding covered stents (Fluency; Bard Inc., Tempe, AZ).

Candidates for endovascular thoracoabdominal aneurysm repair typically are considered to be high risk for open aneurysm repair due to their age, aneurysm morphology, or comorbid conditions. Preoperative assessment typically includes a functional cardiac stress test followed by selective coronary angiography if necessary, transthoracic echocardiography, pulmonary function testing, routine blood work, and a physical examination. A clear understanding of the aortic, iliac, and femoral anatomy is critical to patient selection and device construction. High-resolution computerized tomography (CT) scans of the entire aorta are analyzed with multiplanar reconstructions and centerline of flow measurement techniques on a workstation (TeraRecon Inc., San Francisco, CA), using 3-dimensional (3D) image analysis techniques to assess the aortic morphology. Chronic aortic dissection and severe iliac disease are potential contraindications to a pure endovascular approach, and hybrid-type repairs are considered in these patients if they are not amenable to open surgical repair.

Spinal drainage is selectively employed based on the extent of aortic coverage (type I, II, and III thoracoabdominal aneurysms) or in the setting of prior aortic surgery, internal iliac, or subclavian/vertebral disease where collateral flow to the spinal cord is potentially compromised. Regional anesthesia may be used for patients with significant pulmonary dysfunction. Patients with renal insufficiency routinely receive hydration and N-acetyl cysteine perioperatively.

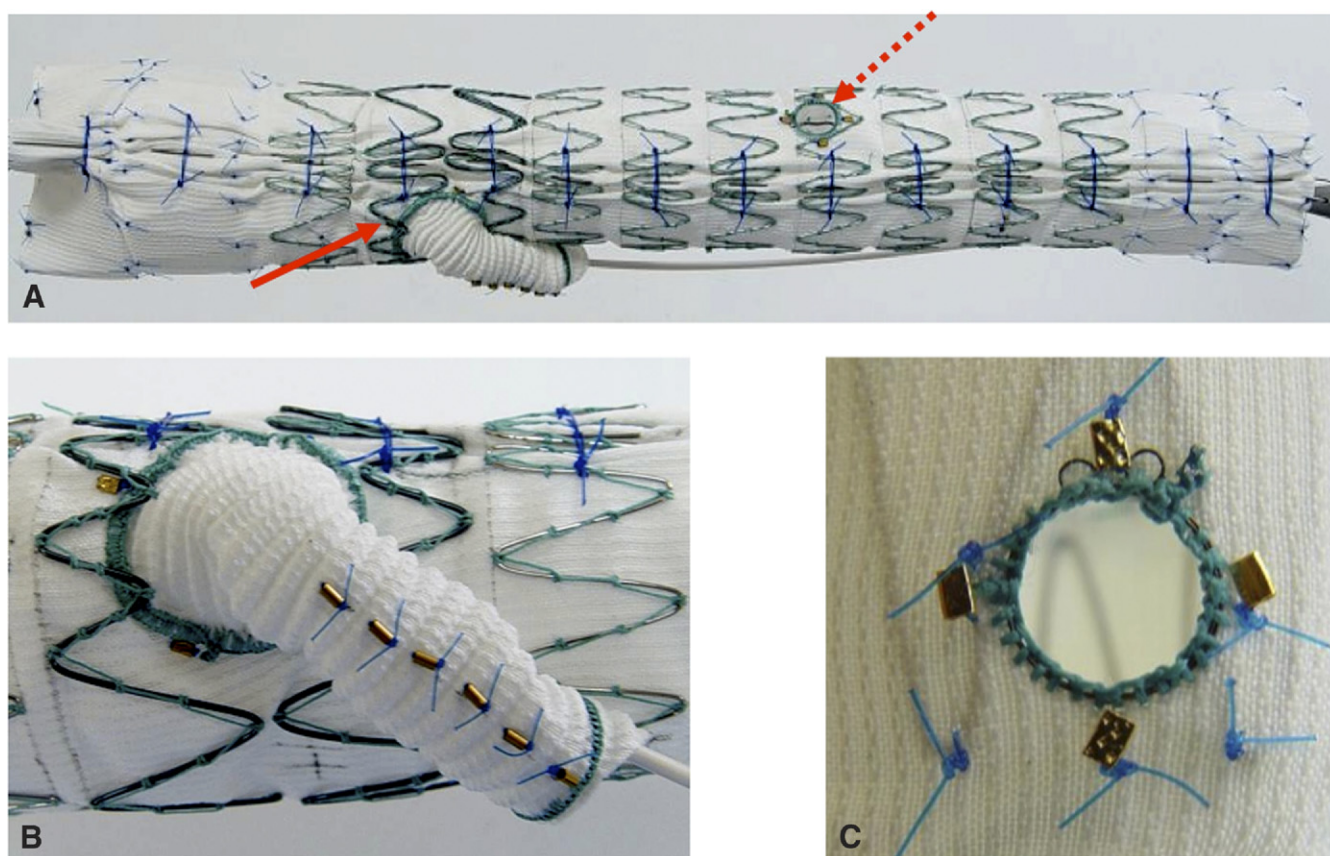
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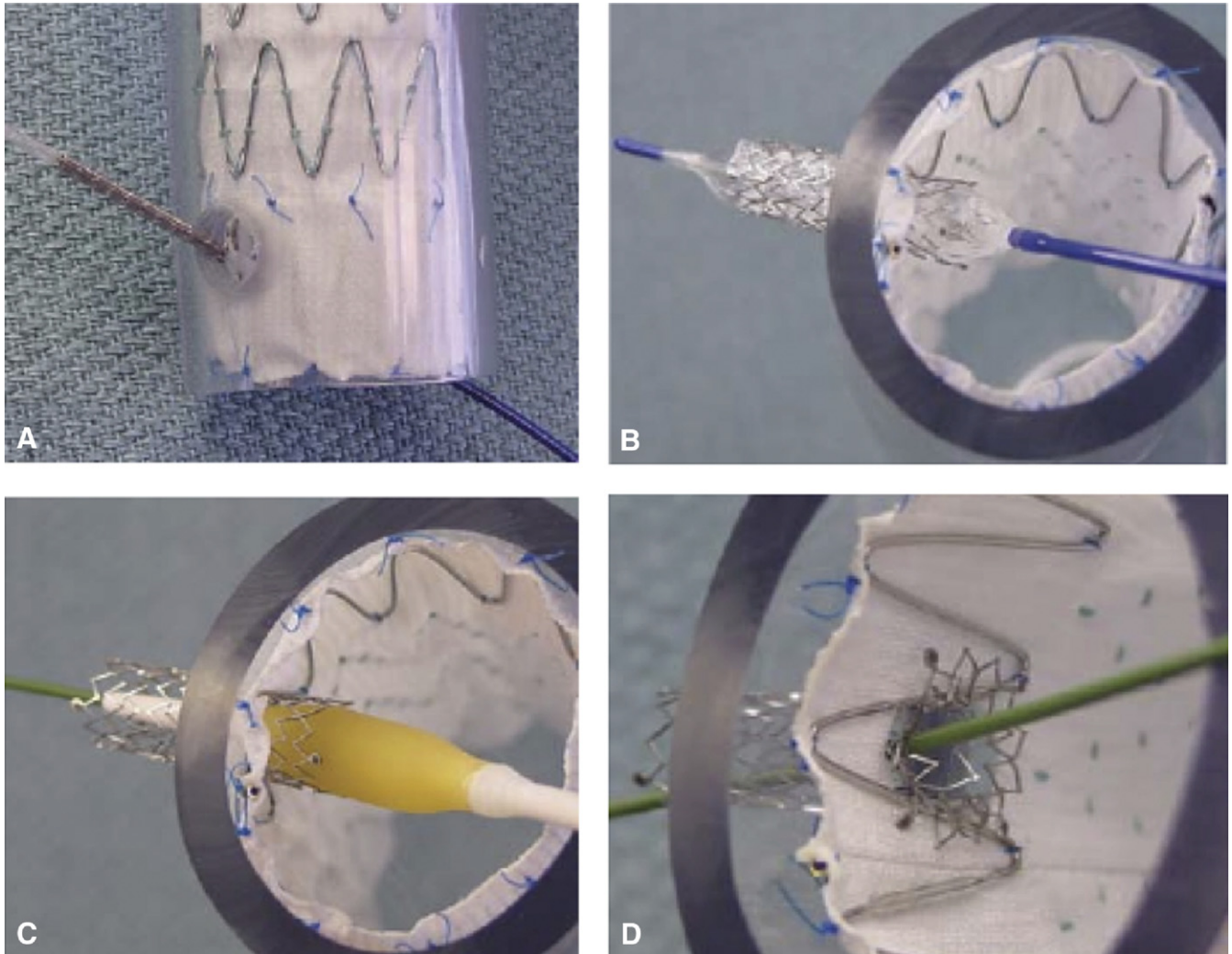
## Operative Technique



**Figure 1** (A) Custom-designed main body device tethered to the delivery system demonstrating branch fenestrations for the renal arteries and a helical branch providing antegrade perfusion of the celiac artery. The helical branch for the superior mesenteric artery (SMA) and fenestration for the contralateral renal artery are out of view.

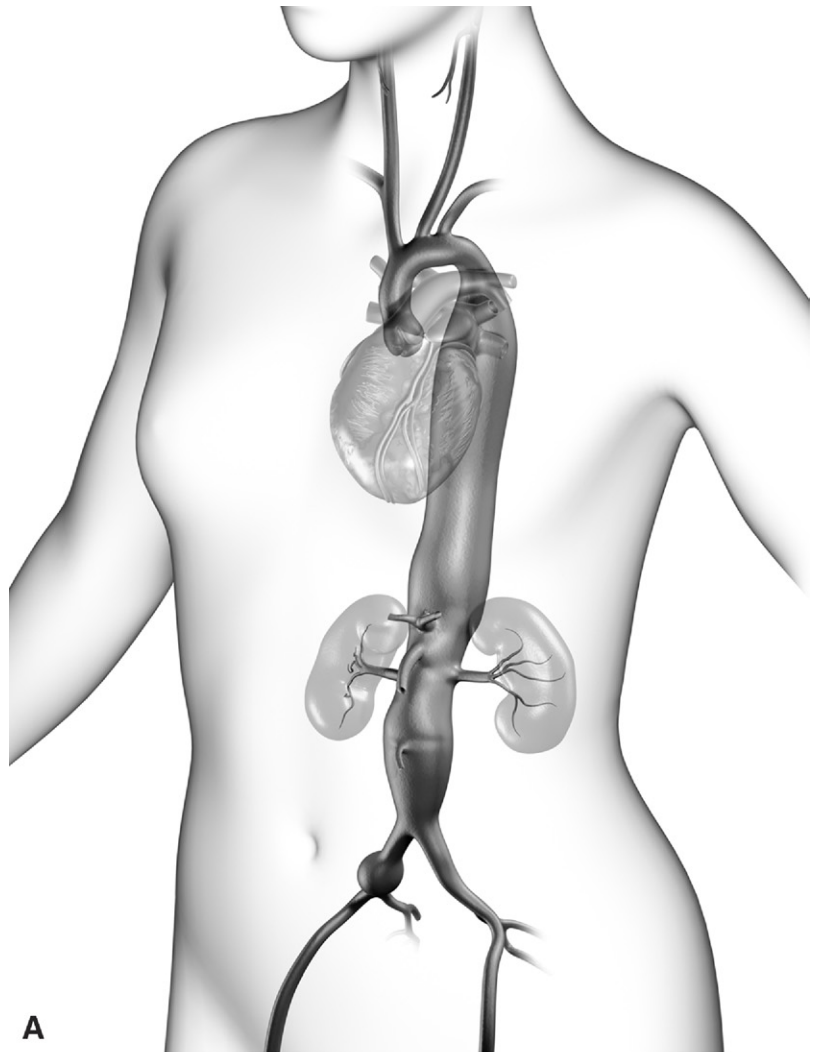
(B) The helical branch is an 8-mm polyester graft sewn to the aortic prosthesis above the target vessel. The branch is wrapped in a spiral fashion external to the aortic prosthesis, orientated in either an antegrade (as shown) or a retrograde fashion, and terminated proximal to the target vessel. These so-called directional branches provide long regions (2 cm) of overlap, allowing mating of a self-expanding stent-graft (Fluency) sized to the visceral vessel. The helical branch construct provides a more secure seal into both the mating vessel and the aortic component given the extensive potential for overlap with both sealing regions, resulting in less of a tendency to develop endoleaks or component separation. Cannulation of the helical branch from a brachial or axillary approach is made easier by a preloaded access catheter traversing the branch.

(C) The fenestrated branch is a nitinol-reinforced opening in the main body device that is sized and aligned with the target vessel ostium. This is mated with a balloon-expandable stent-graft lumen and the aortic portion is subsequently flared with a compliant balloon to achieve a seal around the fenestration. Alignment of fenestrations with target arteries is accomplished by leaving the main body device partially constrained, ensuring the ability to rotate the device to establish radial orientation, and adjusting the longitudinal position to ensure cranial/caudal alignment while selective cannulation of each artery is accomplished through the main body device.

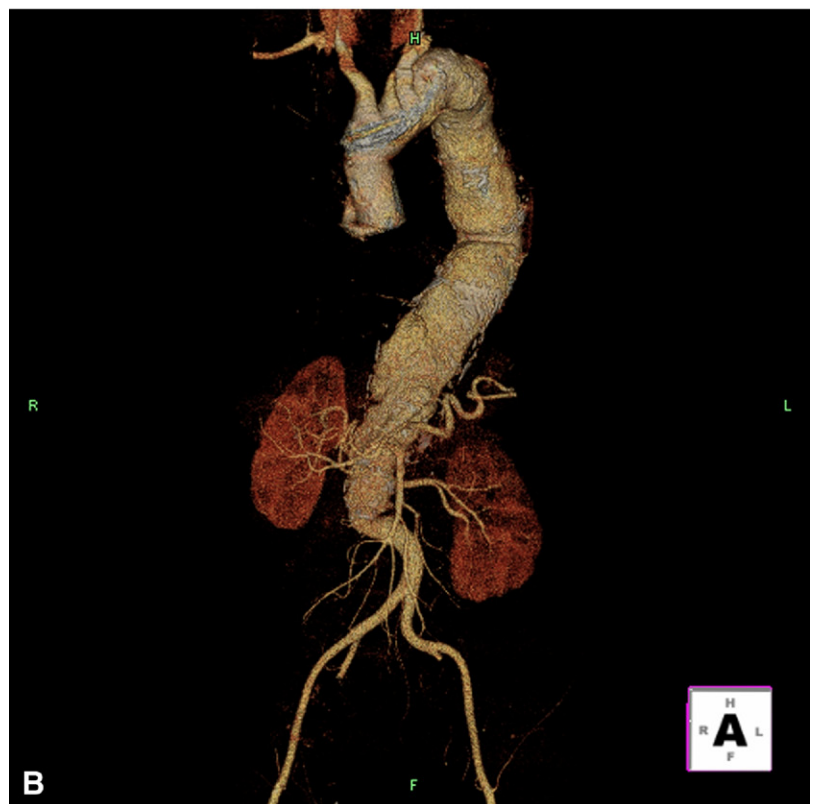


**Figure 2** The aneurysm is excluded using a fenestrated endograft by coupling the aortic component with a balloon-expandable stent that is placed through the fenestration. A stent-graft is placed into the target vessel through the graft fenestration (A). The balloon-expandable stent is deployed, leaving a portion of the stent within the main body of the graft (B). A larger balloon is placed inside the proximal portion of the deployed stent (C). Inflation of this balloon results in flaring of the aortic portion of the stent and creation of the seal (D). (Reprinted with permission from Greenberg RK. Endovascular aneurysm repair using branched or fenestrated devices. *Endovascular Today*, March 2005, 180.)





**Figure 3** Endovascular repair of a thoracoabdominal aortic aneurysm requires careful preoperative planning.<sup>4</sup> Appreciation of the 3D aortic topography is essential to proper patient selection, device design, and accurate delivery. Important anatomic details include a clear understanding of the relationships of all the visceral and renal branches to each other, degree of aortic calcification, length and tortuosity of proximal and distal seal zones, and evaluation of iliac access. High-resolution CT scans are acquired to evaluate the entire aorta and assessed on a 3D imaging workstation (TeraRecon). Pictured is a type II thoracoabdominal aneurysm (A) with the associated 3D CT reconstruction (B).



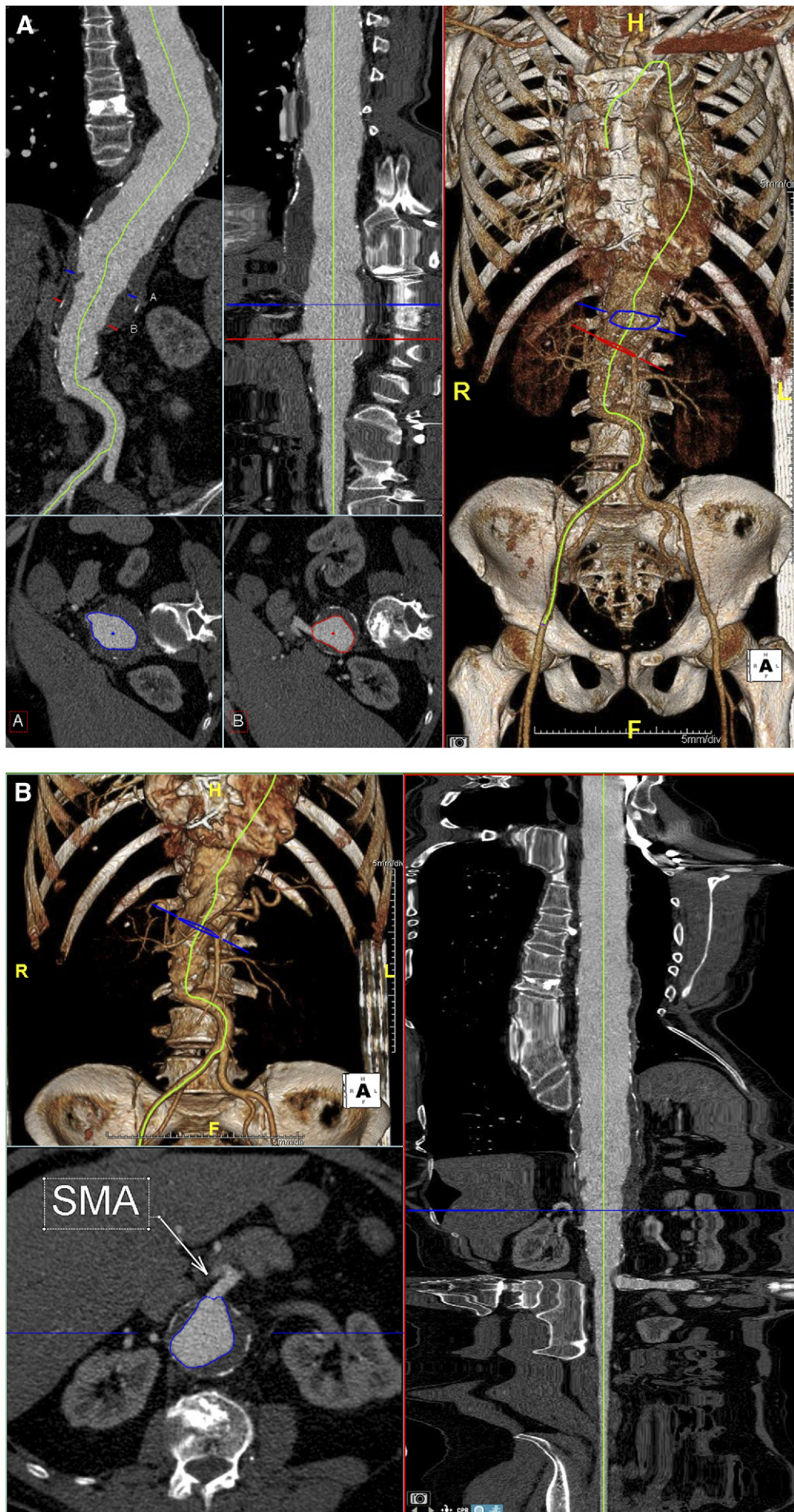
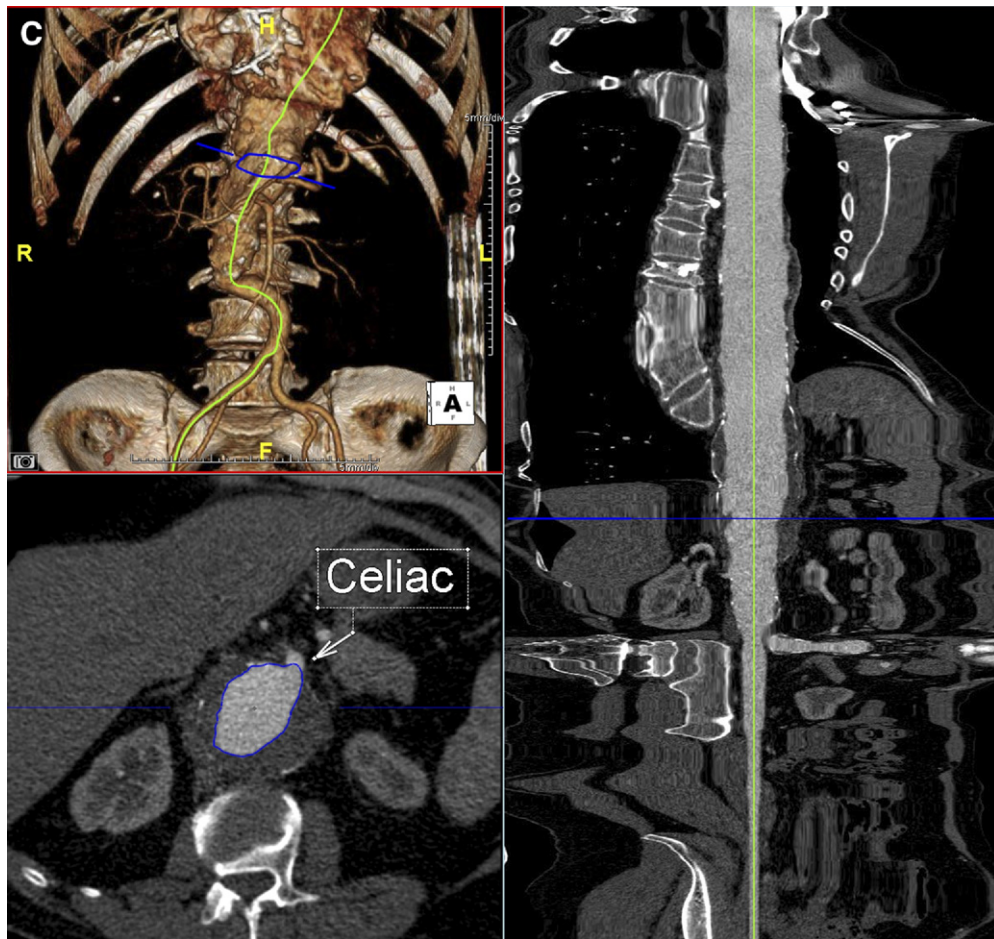
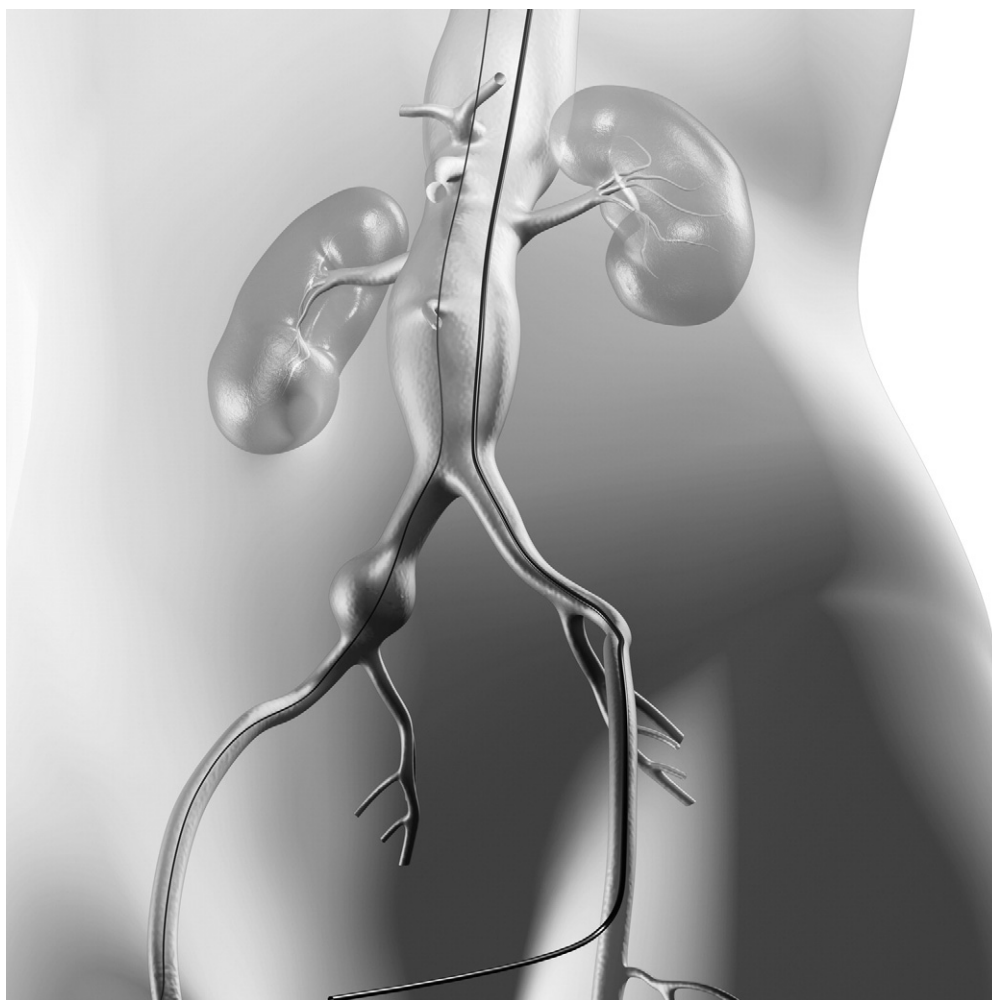


Figure 4



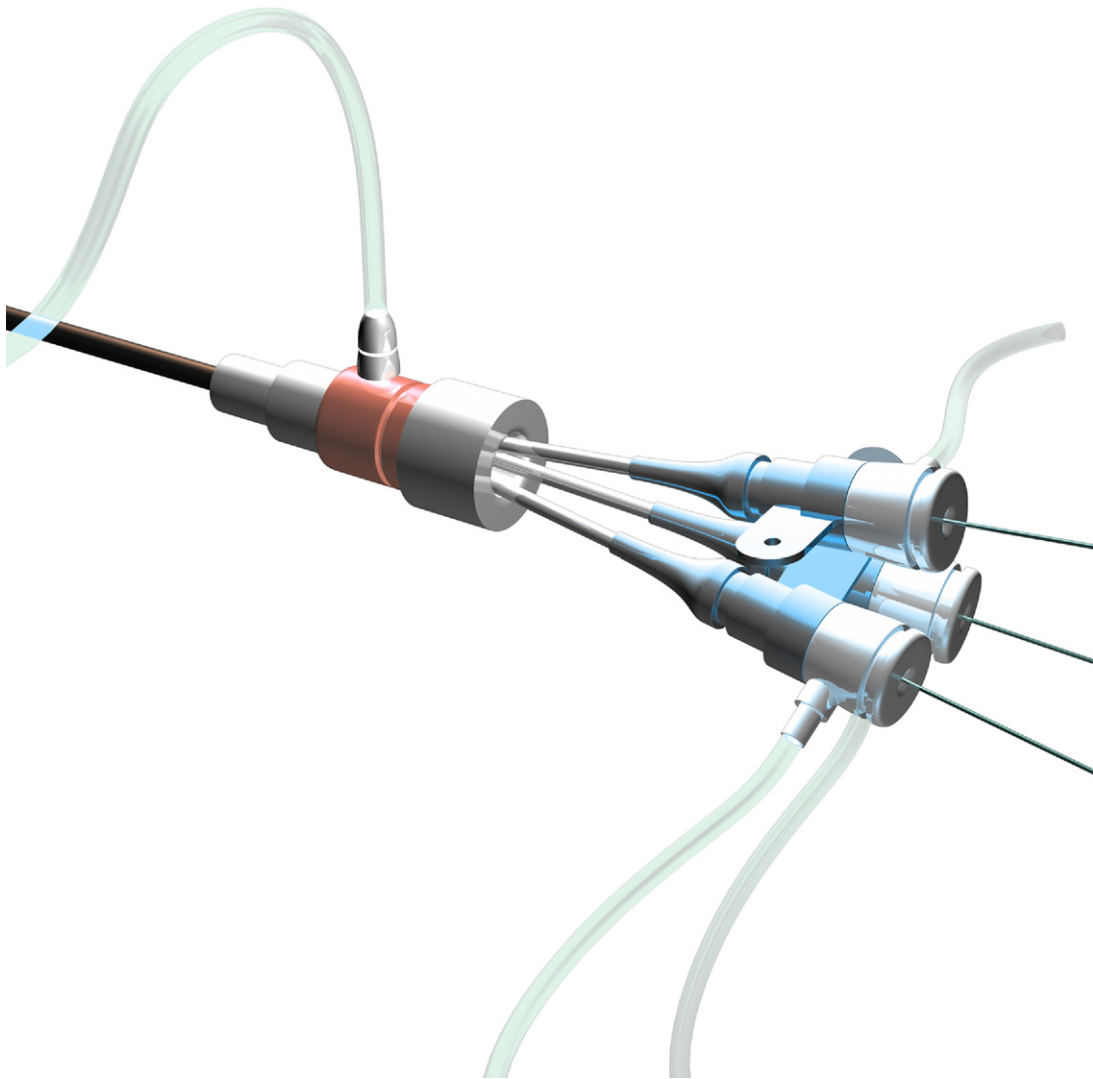


**Figure 4** (Continued) Accurate planning and construction of the custom-designed branched thoracoabdominal stent-graft require detailed computerized 3D modeling to provide a 360° view of the aortoiliac and visceral branch anatomy. Centerline of flow analysis allows the surgeon to generate a straightened image of the aorta and assess the precise angle of visceral branches as well as the distance between branches (A). Orthogonal slices through the centerline of flow provide measurements that are then used for branched stent-graft construction. These reference points are usually described as a location from the origin as noted on a clock face (B, C). SMA = superior mesenteric artery.



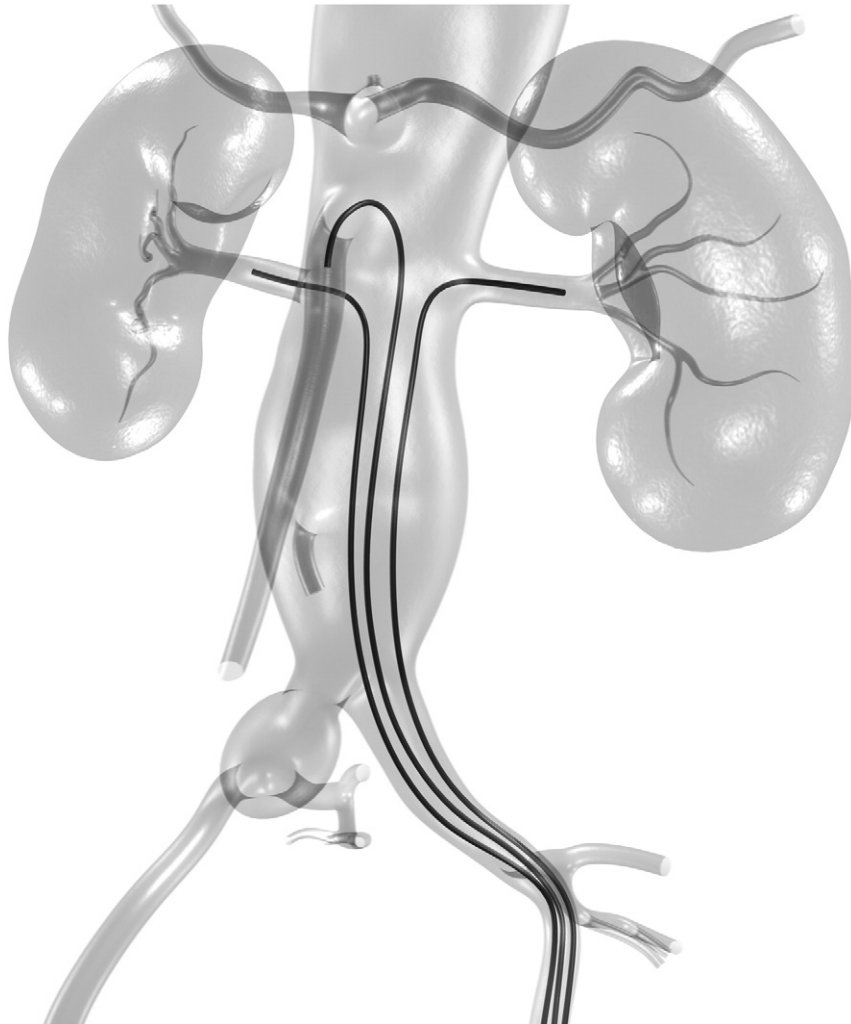
**Figure 5** An endovascular suite fitted with a fixed imaging system is optimal to perform these procedures. General or regional anesthesia may be used, as may spinal drainage catheters. Retroperitoneal access to the iliac artery may be necessary when the vessels are small or badly diseased; thus, all equipment for an open surgical case should be readily available.

Oblique incisions are made in each groin and a longitudinal incision in the left and/or right deltopectoral grooves. The femoral arteries are controlled with vessel loops as are the left axillary artery. Access is gained in the common femoral artery on the side of delivery, and a catheter is then directed to the ascending aorta, and exchanged for a stiff guidewire (0.035 Amplatz or Lunderquist). A large-bore (20-24 Fr Check-Flo; Cook) sheath is then placed in the contralateral femoral vessel. After arterial exposure is completed, heparin is administered.

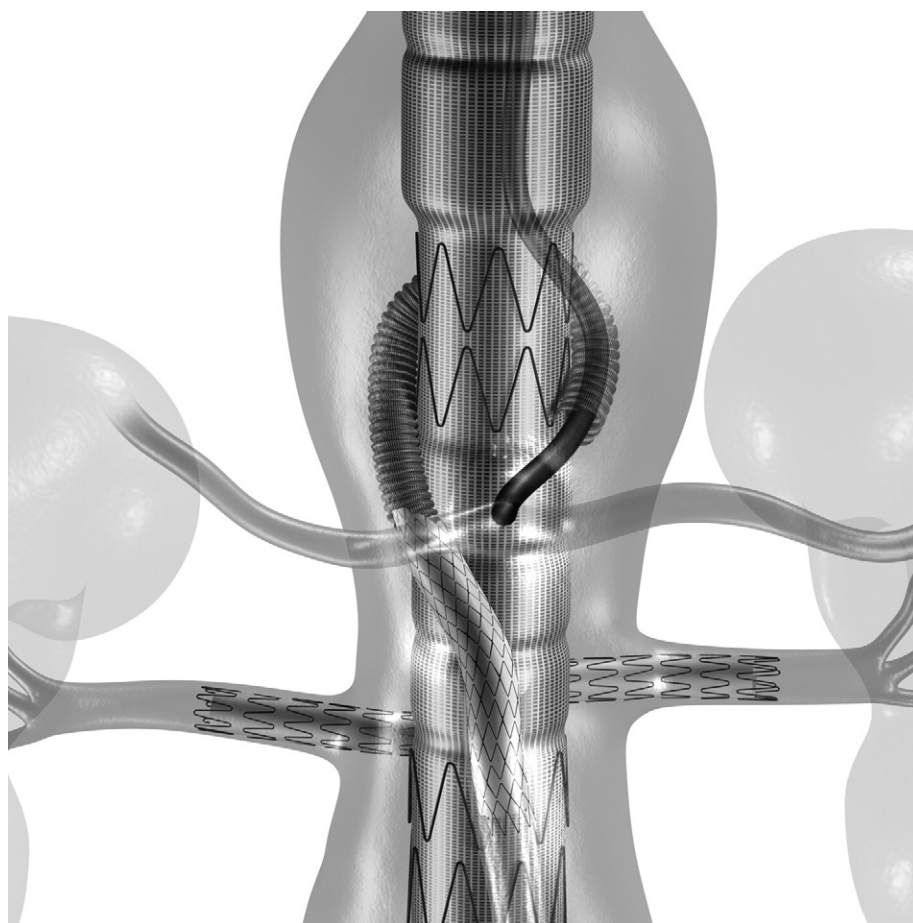


**Figure 6** The large-bore sheath is multiply punctured with short small sheaths. (Color version of figure is available online at <http://www.optechts.com>.)





**Figure 7** Access is then gained into the renal arteries and the SMA. A straight angiography catheter is then positioned at the level of the diaphragm, and angiography may be performed if required to further delineate the visceral segment.

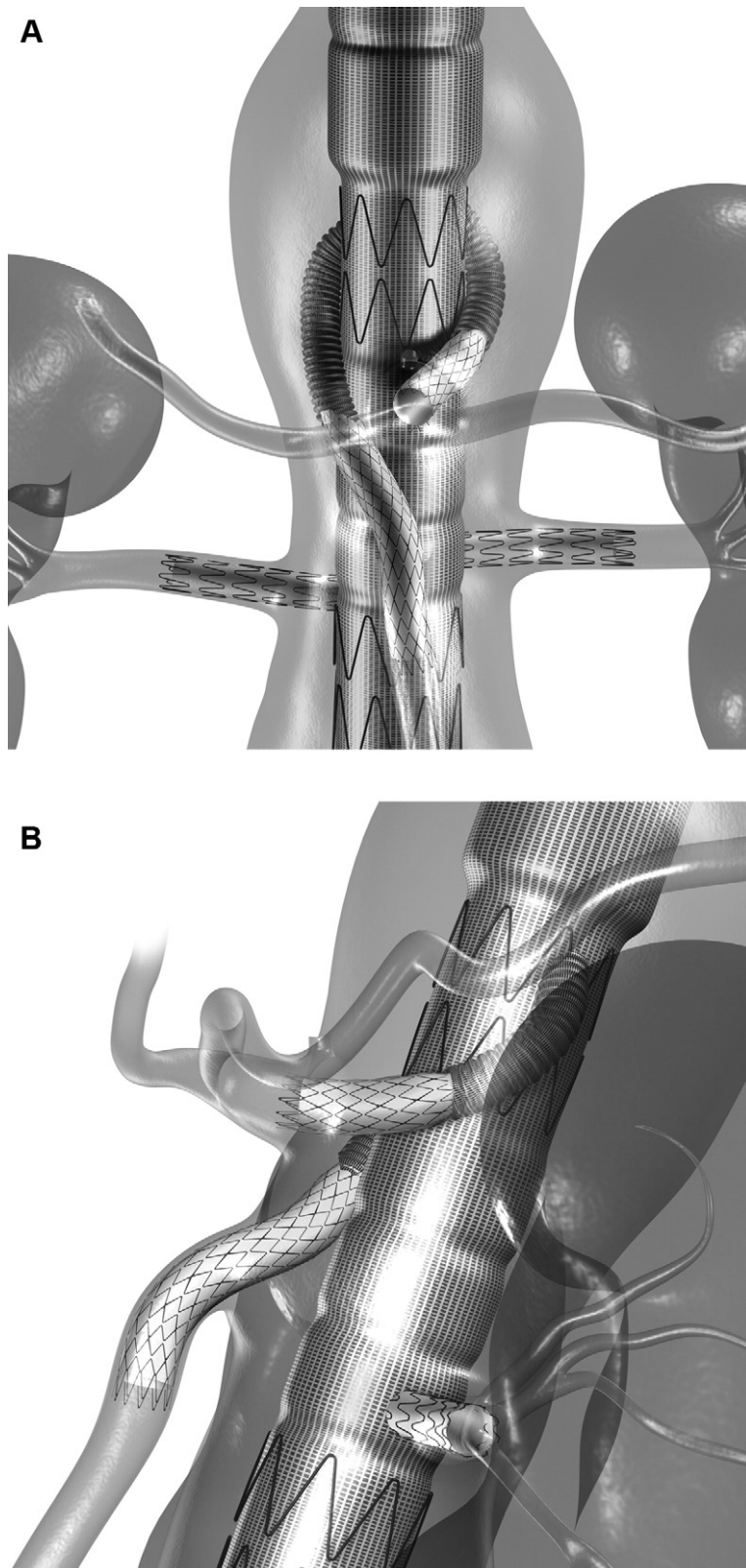


**Figure 8** The main body device is then orientated outside the body, keeping in mind the necessary position for branches and fenestrations. The device is then advanced through the femoral artery to the level of the visceral segment and aligned with the appropriate branch arteries. Multiple low-dose contrast injections may be needed at this step to confirm accurate placement. Gold markers on the fenestrations and helical branches assist in this process.

A long hydrophilic wire (St. Jude Medical, Minnetonka, MN) is then preloaded into the celiac catheter of the main body device, advanced into the arch, and snared from the left axillary access. This now provides through-and-through access to the celiac helical branch. The 2 top stents are then partially deployed, and the device position is repositioned if necessary by adjusting the longitudinal and rotational planes. The main body device sheath is then completely removed to allow partial expansion of the device; the remaining constraining wire prevents full deployment.

The renal fenestrations are cannulated by gaining access into the main body of the device from the contralateral groin. Typically angled or reverse curved catheters coupled with hydrophilic wires are utilized. After obtaining catheter access, flexible, steerable wires are exchanged for stiffer wires (Rosen), to allow for the introduction of a larger sheath (7-Fr Ansel) or guiding catheter (8-Fr Multi-Purpose B [MPB]). This process is repeated for each fenestration.

The helical branches are mated with self-expanding stent-grafts, which require larger delivery sheaths. A 9 mm × 80 cm sheath is then brought down from the left axillary artery over the through-and-through wire into the celiac helical branch; the sheath is doubly punctured and an access deep into the celiac vasculature is established with a catheter and wire, that is then exchanged for a stiff (Amplatz) wire. The second preloaded wire is then snared via the other axillary artery, again providing through-and-through wire access. A second 9 mm × 80 cm sheath is advanced into the SMA helical branch, and an Amplatz wire is placed into the SMA proper. The helical branches can be done simultaneously or in a staged fashion, depending on the status of the arch and tortuosity of the proximal aorta.



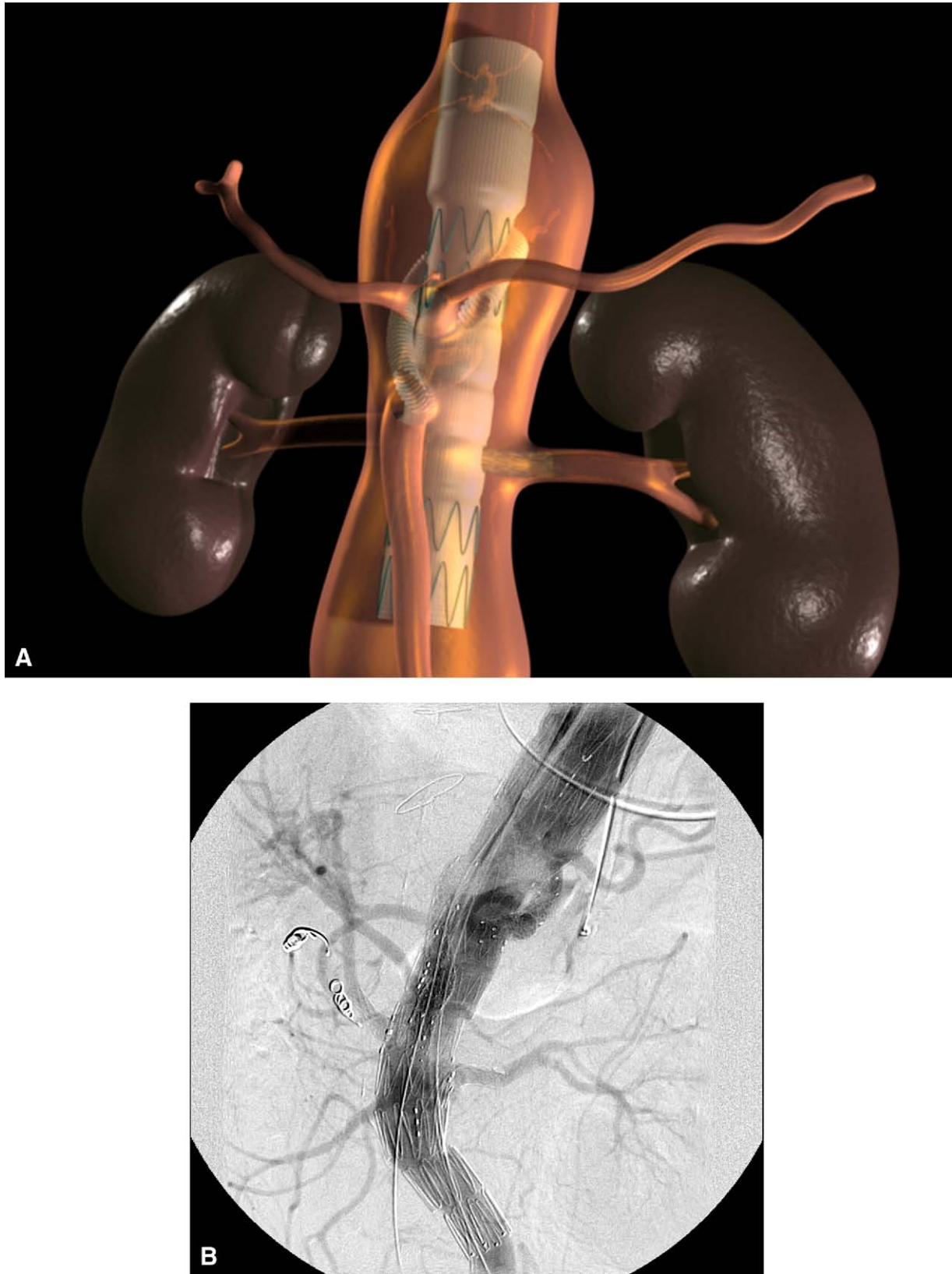
**Figure 9** Once access has been obtained into each of the target vessels, ensuring that no additional movement of the aortic component is required, the constraining wire is released and the main body of the device is fully expanded, but remains attached to the delivery system proximally and distally. Each branch vessel is then adjoined to the aortic device with the chosen stent-graft.

Balloon-expandable covered stents (Jomed) measuring 18 to 38 mm in length that can be expanded to either 4 to 9 mm in diameter or 6 to 12 mm in diameter (depending on the thickness of the covering) are then deployed on 6- to 8-mm balloons (sized to the renal artery diameter), leaving approximately 3 mm of the stent-graft extending into the aortic portion of the device. This segment is then flared with a 10- to 12-mm balloon to flare the visceral stent-graft within the aortic graft, achieving a seal around the nitinol ring.

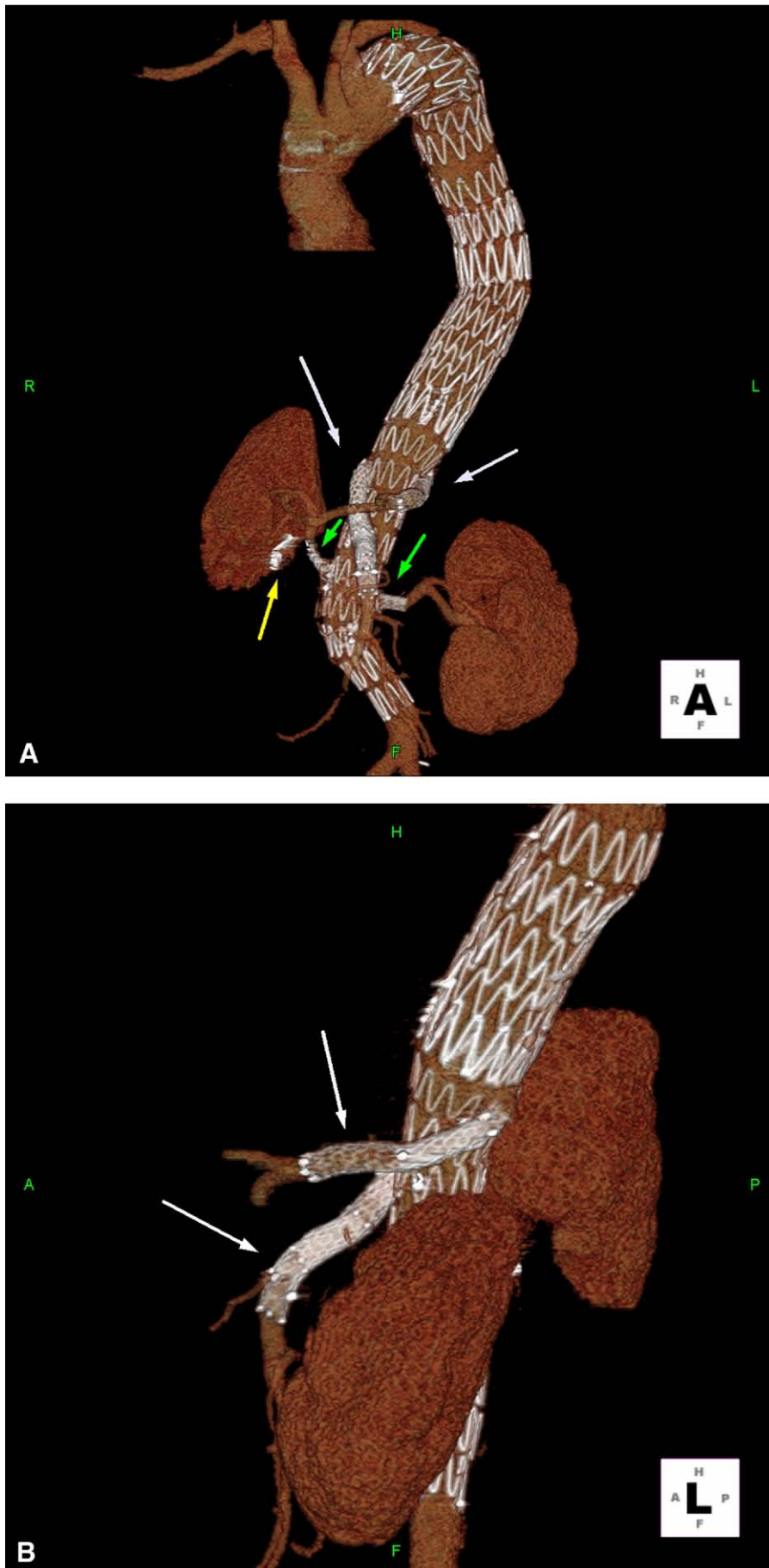
Self-expanding stent-grafts that are typically 10 mm in diameter stent-grafts (Fluency) are advanced via the axillary access to bridge between the side-arm helical branch and target visceral vessel. Balloon-expandable stents may be needed to reinforce the branch if there is marked tortuosity or visceral artery stenoses.

Antero-posterior (A) and lateral (B) views of the completed visceral segment detail the fenestrated and branched stents extending from the main-body device. Proximal thoracic extension grafts are used to bridge the main body device to the proximal landing zone. Distal bifurcated iliac or internal iliac branched components are also added as required.





**Figure 10** Completed visceral segment branched endograft (A). Completion angiography (B) is performed from above and below the visceral component to ensure proper placement and ascertain for endoleaks. Groin and axillary access is repaired after wires and sheaths are removed, and protamine is administered to reverse the heparin. Patients are returned to the intensive care unit and, if a spinal drain was inserted, it is typically continued for 72 hours, at which point a CT is obtained to confirm aneurysm exclusion. Other than aspirin, no anticoagulation is prescribed.



**Figure 11** Anterior (A) and lateral (B) views of a completed repair with a branched endovascular stent-graft. (Reprinted with permission from Greenberg RK et al.<sup>3</sup>)

## Postoperative Care

Spinal drainage is continued for 72 hours or until a CT confirms aneurysm exclusion. Mean arterial pressure is maintained above 85 mm Hg to prevent spinal cord ischemia. Imaging and clinical evaluations are performed at 1, 6, and 12 months and annually thereafter.

## Results

Greenberg and coworkers reported the first 50 patient series of branched endografts used to treat thoracoabdominal aortic aneurysms.<sup>5</sup> Despite the high-risk patient cohort, there was only 1 (2%) perioperative death and 2 cases (4%) of spinal cord ischemia. Roselli and coworkers described 73 patients who underwent fenestrated-branched endograft repair for type I, II, or III ( $n = 28$ ) and type IV ( $n = 45$ ) thoracoabdominal aortic aneurysms between 2004 and 2006.<sup>6</sup> Mean aneurysm size was 7.1 cm. Thirty-day mortality was only 5.5%; mean length of stay was 8.6 days. Major perioperative complications occurred in 11 patients (14%) and included paraplegia (2.7%), renal failure (1.4%), prolonged ventilator support (6.8%), myocardial infarction (5.5%), and minor hemorrhagic stroke (1.4%). Target branch vessel patency was 100%.

The largest series to date of endovascular thoracoabdominal repair has been reported by our group at the Cleveland Clinic.<sup>3</sup> Greenberg and coworkers compared 352 endovas-

cular thoracoabdominal repairs (ER) with 372 open surgical repairs (SR). Mortality was equivalent at 30 days (5.7% ER versus 8.3% SR,  $P = 0.2$ ) and at 12 months (15.6% ER versus 15.9% SR,  $P = 0.9$ ). Spinal cord injury was borderline lower in the endovascular repair group (4.3% ER versus 7.5% SR,  $P = 0.08$ ). These results are extremely encouraging for the higher risk thoracoabdominal patient. Because of this data, we routinely screen descending or thoracoabdominal aneurysm patients for their anatomic suitability for branched-fenestrated stent-graft repair.

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